DEVELOPMENT OF CRITERIA FOR USING THE SUPERPAVE GYRATORY COMPACTOR TO DESIGN AIRPORT PAVEMENT MIXTURES

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ABSTRACT

It is important that the Superpave asphalt mix design method be adopted as an option for airfield pavements. The design of asphalt mixtures for airfields has been accomplished using the Marshall method since the 1940's. The Superpave design method was developed and adopted by state DOTs beginning in the mid 1990's and, currently, most transportation departments have adopted this concept. Since most of the paving work by the asphalt industry is funded by state DOTs and private work (which typically use DOT criteria), it is becoming more difficult to find laboratories and contractors that continue to use the Marshall method. This study evaluated the number of gyrations for a number of mixtures required to provide a density equal to 75 blows with the Marshall hammer. Since the 75 blow Marshall mixture had performed well in the past it was believed that providing a density with the gyratory compactor equal to that obtained with Marshall compaction would be a good way to adopt Superpave and still have confidence of good performance. This paper describes the details of the study and provides a recommended number of gyrations with the Superpave gyratory compactor to provide a mixture that will perform similar to 75 blow Marshall mixture.

INTRODUCTION

Hot mix asphalt (HMA) mixtures traditionally have been designed in the laboratory prior to construction [1]. The laboratory mixture design is intended to evaluate the combined properties of the aggregate and asphalt cement mixture with the best compromise of desirable properties. Although several mixture design methods have been developed over the years, the Marshall method has been predominantly used by the Federal Aviation Administration (FAA) for designing HMA mixtures for airports [2].

In the mid 1990s, the Strategic Highway Research Program (SHRP) introduced the Superior Performing Asphalt Pavements (Superpave^{TM}) laboratory mix design procedure. This method is based on compaction of HMA specimens using a Superpave gyratory compactor [3].

The Superpave HMA mix design procedure has been adopted by nearly every state department of transportation and is used for all categories of roadways including highways and interstates. Consequently, contractors or testing laboratories maintain capabilities and are experienced in using the Superpave method. In the future, organizations continuing to use the Marshall mix design method will encounter increasing difficulty in finding contractors and testing laboratories experienced and accredited in the Marshall mix design method.

ASPHALT MIX DESIGN METHODS

Marshall Method

Bruce Marshall developed the Marshall method in the late 1930s while employed by the Mississippi State Highway Department [1, 4]. The Marshall procedure showed promise and was adaptable for field use. As a result, the Marshall procedure was heavily researched during the mid 1940s at the U.S. Army Engineer Waterways Experiment Station (WES). The method was adopted by the U.S. Army Corps of Engineers during World War II, with some modifications for designing asphalt paving mixes for airfield pavements [5]. Modifications to the procedure were made to match laboratory densities with densities of field-compacted pavements [6].

Until recently, the Marshall method was widely used for HMA mix design in the U.S. and around the world for roadways and for airport pavements [7]. Wide-spread use of the Marshall method has been attributed to laboratory compaction closely representing field compaction as well as ease of application and portability.

Current design procedures for airport pavements incorporate two levels of compaction: 50 blows and 75 blows [2, 8]. These levels of compaction correspond to anticipated pavement traffic. Pavements with expected heavy wheel loads or high tire pressures are designed with the 75-blow method, which includes criteria for stability (≥ 2,150 lb) and flow values (10-14) using the 75-blow method.

Superpave Method

As a result of research funded under the SHRP, which was completed in the mid 1990s, the Superpave mix design procedure was developed [9]. The concept included a new approach to binder grading and selection, adoption of comprehensive aggregate requirements, new aggregate gradations, new laboratory compactor, volumetric requirements, and moisture sensitivity requirements [9]. A new mix design procedure was sought to provide a balance between competing problems of durability, cracking, and rutting associated with HMA pavement performance. A major influence on designing durable, rut-resistant pavements is the laboratory compaction used to replicate field compaction, because the compaction is directly related to the binder content. Therefore, selection of the Superpave compactor was important.

Superpave for Airport Pavements

At the conclusion of the SHRP, a study was conducted to evaluate the products for their applicability to airport pavements. Newman and Freeman produced a report for the FAA reviewing all SHRP products [10]. Products involving the Superpave system included aggregate characteristics and gradations, mix design system, gyratory compactor and compaction levels, and binder specification, among others. The gyratory compactor and binder specification were determined to be applicable to airport pavements with minor revisions. Further research was recommended to provide data for determining changes to each product prior to implementation.

The Airfield Asphalt Pavement Technology Program (AAPTP) was developed in 2004 by the FAA to address technology gaps and to provide improved construction guidance for airport asphalt pavements to enhance performance, durability, and cost effectiveness [11]. In a study funded under the AAPTP, Cooley [12] recommends changes to the current FAA criteria that will allow the use of the SGC to design HMA mixes for airports. These recommendations are given in Table 1.

Prior to Cooley's report, the FAA produced criteria for using Superpave methodologies for designing airport pavements [13]. These criteria (Table 2) include recommendations for binder performance grade, aggregate gradations, and gyratory compaction levels.

Table 1.
Superpave Compaction Requirement Recommended by AAPTP 04-03.

Test Property		Pavements Designed for Design Aircrafts with Tire Pressures of		
		< 100 psi	100 - 200 psi	> 200 psi
Initial Gyration Level		6	7	7
Design Gyration Level		50	65	80
Required Relative Density, Percent of Theoretical Maximum Specific Gravity	$N_{initial}$ [a]	≤ 90.5	≤ 90.5	≤ 90
	N_{design} [b]	96.0	96.0	96.0

[a] $N_{initial}$ is the number of gyrations that ensures that an asphalt mix does not compact too readily.
[b] N_{design} is the number of gyrations that results in the desired air void content of a compacted HMA specimen.

Table 2.
FAA Superpave Design Criteria.

Pavements for gross aircraft weights of 60,000 pounds or more		
Test Property	Design Criteria for Nominal Maximum Aggregate Size	
	¾" Nom. (19 mm Nom.)	½" Nom. (12.5 mm Nom.)
Initial Number of Gyrations ($N_{initial}$)	8	8
Design Number of Gyrations (N_{design})	85	85
Maximum Number of Gyrations (N_{max})	130	130
Air Voids @ N_{design}	4.0	4.0
Voids in Mineral Aggregate @ N_{design}, %	13.0 min.	14.0 min.
Voids filled with Asphalt @ N_{design}, %	65-78	65-78
Dust proportion	0.6-1.2	0.6-1.2
Dust proportion (coarser gradations[a])	0.6-1.6	0.6-1.6
Fine Aggregate Angularity	45 min.	45 min.
%G_{mm} @ $N_{initial}$	≤90.50	≤90.50
%G_{mm} @ N_{max}	≤98.00	≤98.00

[a] A coarse gradation is defined as a gradation passing below the restricted zone. The restricted zone is defined in the Asphalt Institute's Manual Superpave, Series 2 (SP-2).
Source: FAA Engineering Brief 59A, 2006

RESEARCH OBJECTIVE AND SCOPE

The purpose of this study was to determine the number of gyrations required to produce a degree of compaction so that suitable binder content can be selected for airport HMA. This study was conducted simultaneously with an AAPTP study. In this study, volumetric properties of specimens produced by the 75-blow Marshall compaction effort (hand held hammer) are considered to be acceptable for pavements with aircraft gross weights of greater than 60,000 lb or with tire pressures greater than 100 psi. For this work, specimens from 52 asphalt paving mixes were compacted using the 75-blow Marshall manual compaction effort. Specimens from these mixes were also compacted with the Superpave gyratory compactor to determine the number of gyrations required to produce a compacted specimen density equivalent to the

Marshall specimens. Analysis of data from the Superpave gyratory compaction procedure was used to develop recommendations for using the Superpave gyratory compactor to select the design binder content for airport paving mixtures.

The aggregate gradations and design binder content for each combination of test variables was selected based on criteria in Advisory Circular AC 150/5370-10B, Item P-401, “Plant Mix Bituminous Pavements.” The results and discussion in this document include data from asphalt mixes that meet specifications of the current version of Item P-401.

For this study, thirty-two aggregate combinations were tested. These combinations included variations in maximum aggregate size (½, ¾, and 1 in.), aggregate type (limestone, granite, and chert gravel), gradation (upper and lower limits of Item P-401 specification band), and percentage of natural sand (0 and 10 percent). Because the chert gravel and limestone aggregate had a maximum particle size of ¾ in., blends meeting the requirements for a 1-in. maximum aggregate size were not evaluated. Additionally, only one gradation of chert gravel aggregate with a ½-in. maximum aggregate size was used because variations of the gradation did not meet Marshall stability criteria.

The 75-blow Marshall compaction effort (hand held hammer) was used to identify the design binder content for each mix. The design binder content in this study is the asphalt cement (AC) content that resulted in a compacted specimen having a density of 96.5 percent of the maximum theoretical density. This density corresponds to an air content of 3.5 percent. This air content was selected as the middle of the range of allowable air contents (2.8-4.2 percent) in Item P-401 [2]. Superpave gyratory compacted specimens were prepared at this design binder content. The number of gyrations required to obtain 96.5 percent of the maximum theoretical density was determined. Data for all mixes were then analyzed to identify the target gyration level for designing asphalt mixtures for airfield pavements.

MATERIALS

Asphalt Binder

Two asphalt binders were used in this study. Both were obtained from Ergon Asphalt and Emulsions, Inc. Tests by the distributor indicated the two were a PG 64-22 neat binder and a PG 76-22 polymer-modified binder. Tests indicated both binders had a specific gravity of 1.038. Recommended mixing and compaction temperatures for the PG 64-22 binder were 310°F (154°C) and 290°F (145°C), respectively, and mixing and compaction temperatures for the PG 76-22 binder were 360°F (182°C) and 335°F (168°C), respectively. Mixing and compaction temperatures for the modified binder were higher than those typically used during construction. These temperatures were used in this study to provide equivalent Brookfield viscosities of the binders.

Aggregate

Aggregates used in this study consisted of available material stockpiles. These included limestone, granite, and chert gravel aggregates. The limestone aggregate was from a Vulcan Materials quarry in Calera, Alabama. The granite aggregate was from a McGeorge Corp. quarry in Little Rock, Arkansas. The chert gravel aggregate was from Green Brothers Gravel Company in Copiah County, Mississippi. Additionally, some mixtures were blended with selected percentages of natural sand.

Each aggregate type was represented by multiple stockpiles that were blended to meet the target gradations. Selected gradations were within the allowable range of size fractions according to FAA Item P-401. The gradations in this paper are designated as fine and coarse. Fine gradations are those near the upper limits of the gradation band. Coarse gradations are those near the lower limits of the gradation band. Figure 1 shows examples of fine and coarse gradations used in this study. Some aggregate blends included 10 percent natural sand. These gradations are characterized by a hump in the grain size distribution near the No. 30 (0.595mm) and No. 50 (0.297 mm) sieve sizes [14].

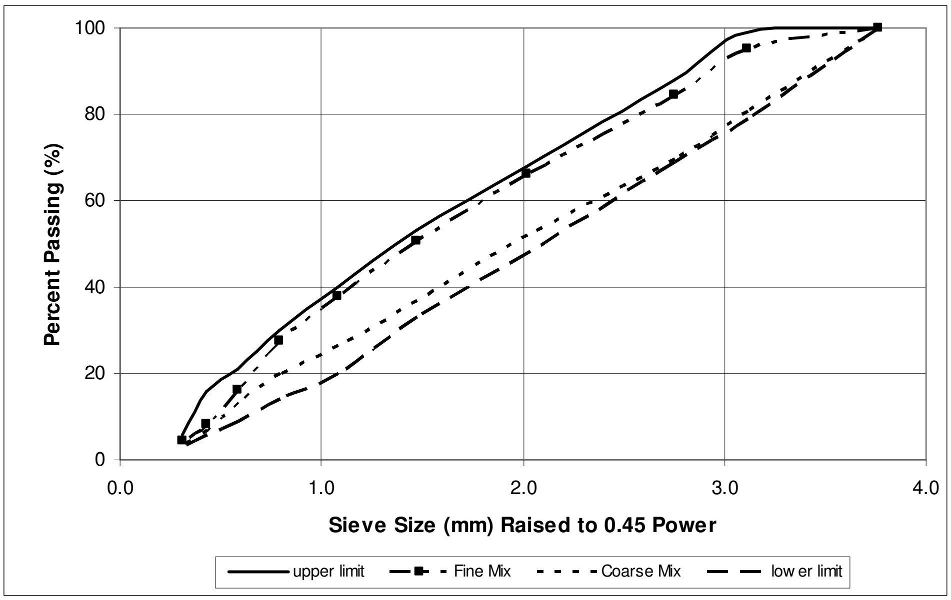

Figure 1. Representative Aggregate Gradations.

The percentages of aggregate with at least two fractured faces [15] were 100, 100, and 97 percent for the limestone, granite, and chert gravel, respectively. The maximum percentages of flat and elongated aggregates [16] were 1.6, 1.0, and 0.3 percent for the limestone, granite, and chert gravel, respectively. Each of the blends met the requirements (8 percent maximum) for aggregate properties required by the FAA for airport pavements.

The fine aggregate angularity [17] for the limestone, granite, chert gravel, and natural sand aggregates was determined by method A of ASTM C 1252 [2]. The limestone, granite, and chert gravel aggregates had a fine aggregate angularity of 47, 47, and 46 percent, respectively. These values are above the minimum value of 45 percent required by the FAA for airport pavement aggregates. The fine aggregate angularity of the natural sand was 40 percent. This value is characteristic of rounded aggregate particles and is typical for natural sands [18].

LABORATORY COMPACTION

Marshall Compaction

The Marshall hand-hammer compaction device was used to produce specimens [19]. In preparation for compaction, the aggregate and binder were heated to the mixing temperature of the asphalt cement. Seventy five blows of the compaction hammer were applied to each face of the specimen. The bulk density of each specimen was then determined according to ASTM D 2726 [20]. Stability and flow values were determined using methods described in ASTM D 6927 [21].

Marshall mix designs are conducted by preparing three replicates at increments of 0.5 percent binder content over a range bracketing the design binder content. The percentage of air voids versus AC content is plotted, and the design binder content is selected at 3.5 percent air voids. The AC content used for compaction with the Superpave gyratory compactor was the design binder content determined with the Marshall design. A summary of the optimum binder content results for all mixtures used is provided in Table 3.

Superpave Gyratory Compaction

Superpave gyratory compaction of asphalt mixes encompasses a range of factors that should be optimized to produce a compacted mixture that accurately represents field compaction. Most of these variables have been fixed through the development of the machine. This study was undertaken to provide a procedure for laboratory compaction and design of airport HMA mixes using the Superpave gyratory compactor that could easily be adopted by design and testing laboratories. Most of the above variables can be directly adopted for use in compacting airport HMA mixes. These included mold size, ram pressure, internal gyration angle, rotational speed, mix temperature, mold temperature, and sample height. This study utilized the standard values, equipment, and procedures used by the highway pavement community. Although the internal gyration angle was not commonly used in practice at the time of this paper, it was selected because research studies suggest the internal gyration angle may produce more consistent compaction than the external gyration angle for different compactor manufacturers. The remaining variable in the mix design procedure needing to be evaluated was N_{design} and is the focus of the following testing.

For this study, a Pine Instruments Company model AFGC125X gyratory compactor was used to produce cylindrical asphalt concrete specimens with a diameter of 6 in. (152 mm) at a target height of 4.5 in. (115 mm). Compaction was performed using a ram pressure of 87 psi (600 kPa) and an internal angle of gyration of $1.16^{o} \pm 0.02^{o}$. Asphalt mixes were compacted to 125 gyrations at a rate of 30 revolutions per minute. Three replicate specimens were compacted for each mix. Each HMA mix was compacted at the design binder content determined from the Marshall mix design using the same aggregate blend proportions. Specimens were tested according to ASTM D 2726 to determine density [20].

Specimens in this study were compacted to 125 gyrations. The maximum gyration level was determined by reviewing state specifications of N_{design}. After this study was initiated, the FAA produced criteria with 85 gyrations as N_{design} (Table 2). The maximum gyration level used in this study was expected to produce air void contents lower than the target of 3.5 percent using the design binder content.

The calculated air content for each specimen was plotted against the number of gyrations to determine the number of gyrations required to compact the specimen to 96.5 percent of its maximum theoretical specific gravity. This value was determined to be $N_{equivalent}$ for each mix. This approach is valid, assuming that the design binder content determined from the Marshall method is the appropriate binder content.

RESULTS AND DISCUSSION

Marshall Mix Design Results

Asphalt mixes with larger maximum aggregate sizes have lower design binder contents than mixes with smaller maximum aggregate sizes. The design binder content was from 0.3 to 0.6 percent lower for mixes with a 1-in. maximum aggregate size than mixes of the same aggregate type and relative gradation designation with a ¾-in. maximum aggregate size. The average difference was 0.4 percent lower. The design binder content was from 0.1 to 0.9 percent lower for mixes with a ¾-in. maximum aggregate size than mixes of the same aggregate type and relative gradation designation with a ½-in. maximum aggregate size. The average difference was 0.5 percent lower. Also, aggregate gradations on the coarse side of the specification band have lower design binder contents than gradations on the fine side of the specification band. Mixes on the coarse side of the gradation band had a design binder content from 0.2 to 1.5 percent lower than mixes on the fine side of the gradation band, and the average design binder content for mixes on the coarse side of the gradation band were 0.6 percent lower than mixes on the fine side of the gradation band. Each of these phenomena is caused by the relative packing ability of the aggregate in each of the mixes and higher surface area of finer aggregates. The major influence on the design binder content for these mixes is the voids in mineral aggregate (VMA). Mixes with higher VMA require more binder to achieve the target air void content.

Table 3: Marshall Mix Design Asphalt Binder Content Results.

Aggregate Type	Binder Grade	Asphalt Content (%)					
		1 in. Maximum Aggregate Size		¾ in. Maximum Aggregate Size		½ in. Maximum Aggregate Size	
		Coarse Mix	Fine Mix	Coarse Mix	Fine Mix	Coarse Mix	Fine Mix
Limestone Aggregate	PG 64-22	--	--	4.8	5.4	5.3	5.5
	PG 76-22	--	--	5.1	5.9	5.5	6.0
Granite Aggregate	PG 64-22	5.0	5.5	5.4	5.9	5.8	6.8
	PG 76-22	5.2	6.0	5.5	6.6	6.0	7.5
Chert Gravel Aggregate	PG 64-22	--	--	6.8	7.4	7.2	--
	PG 76-22	--	--	6.9	7.4	7.1	--

As expected, asphalt mixes containing natural sand generally had a lower design binder content than similar mixes using 100 percent crushed aggregate. Natural sand increases mix compactibility leading to lower VMA and design binder content. Natural sand in mixes causes the design binder content to vary from an increase of 0.2 percent to a decrease of 1.5 percent, with an average decrease of 0.5 percent. These mixes cannot be directly compared because of subtle differences in the aggregate gradations. Adding 10 percent natural sand generally replaces aggregate fractions within the No. 30 to No. 50 sieve size range. The overall aggregate structure is affected and can alter the compacted VMA. The trend of the mixes containing natural sand to have lower design binder contents is due to the rounded sand particle realignment during compaction.

In general, asphalt mixes with limestone aggregate had the lowest design binder content while mixes using the chert gravel aggregate had the highest design binder content among the three aggregate types. The average design binder content for the limestone, granite, and chert gravel aggregate blends was 5.4, 5.8, and 6.5 percent, respectively. These variations in design binder content were attributed to the differences in the VMA of the compacted mixes. The average VMA for the limestone, granite, and chert gravel aggregate blends was 16.2, 16.5, and 17.5 percent, respectively. In particular, chert gravel mixes had a higher VMA than did limestone or granite mixes. The chert gravel is mechanically fractured, but also contains uncrushed faces. The particle shape is angular and does not pack as closely as limestone or granite aggregates that are produced by crushing quarried aggregates. The higher void content of the chert gravel aggregate structure required more asphalt to decrease the air content to the desired level for the compacted mix. The higher VMA for mixes using this gravel source has been previously noted by Ahlrich [22]. The crushed chert gravel has sharp angles that are resistant to degradation, unlike limestone aggregates that may become more rounded during compaction.

Some of the asphalt mixes containing natural sand did not have initial stability values meeting the current Item P-401 criteria of 2,150 lb. These included both the coarse and fine mixes of chert gravel with a ½-in. maximum aggregate size. These mixes were redesigned using a different aggregate gradation to produce a mix that would meet P-401 specifications. This change led to elimination of the coarse and fine gradations of the ½-in. chert gravel mix. The single, revised gradation lay along the median of the ½-in. gradation band. Mixes not meeting stability requirements are not included in the data provided in this document.

The average stability of mixes containing 100 percent crushed aggregate was 2,580 lb while the average stability of mixes containing 10 percent natural sand was 2,530 lb. These differences are insignificant considering that the two results are within the allowable coefficient of variation (6 percent) of the testing procedure [21]. However, the presence of natural sand did appear to impact the compaction behavior of the mixes as indicated by a lower VMA for mixes containing natural sand.

VMA minimum requirements (1 in. – 14 percent, ¾ in. – 15 percent, ½ in. – 16 percent) were met by all mixes described in this document. On average, the VMA of mixes containing natural sand was approximately one percent lower than similar mixes containing 100 percent crushed aggregate. The rounded sand particles enable the aggregates to pack more closely together and reduce the void spaces in the mix. Some mixes had VMA values higher than those typically submitted for a job mix formula for airport construction. It might be anticipated that contractors would redesign the aggregate gradation to approach the VMA minimum values in order to reduce the design binder content and the cost of the asphalt mix.

Superpave Gyratory Compaction Results

A representative set of compaction curves is shown in Figure 2. The figure contains data from three specimens. The curves were generated using the correlation between specimen height and density for each gyration. These curves were used to establish the number of gyrations in the SGC producing 3.5 percent air voids. This number of gyrations is termed $N_{equivalent}$ for each mix. This term designates the number of gyrations required to achieve equivalent density to the 75-blow Marshall manual compaction effort at 3.5 percent air voids. The binder content at 3.5 percent air voids from the Marshall compacted mixes was used as the design binder content for each mix. Table 4 provides the $N_{equivalent}$ values for each mix.

$N_{equivalent}$ values for the different mixes range from 21 to 125 with an average of 69 when comparing the values in the table. However, the values are group averages composed of individual samples with their own variability. Nevertheless, the data indicates that a direct correlation between Marshall and SGC cannot be ascertained using these asphalt mixes.

The SGC is fundamentally different from the Marshall compaction device in the way that asphalt mixes are compacted. The Marshall hammer is an impact device that imparts a similar, repetitive stress to the mix. The SGC provides a kneading action that compacts the mix under constant strain conditions. The SGC mobilizes the aggregate particles to change their orientation. Apparently, the inherent differences in the compaction processes inhibit direct translation of compacted specimen volumetric properties between the two methods.

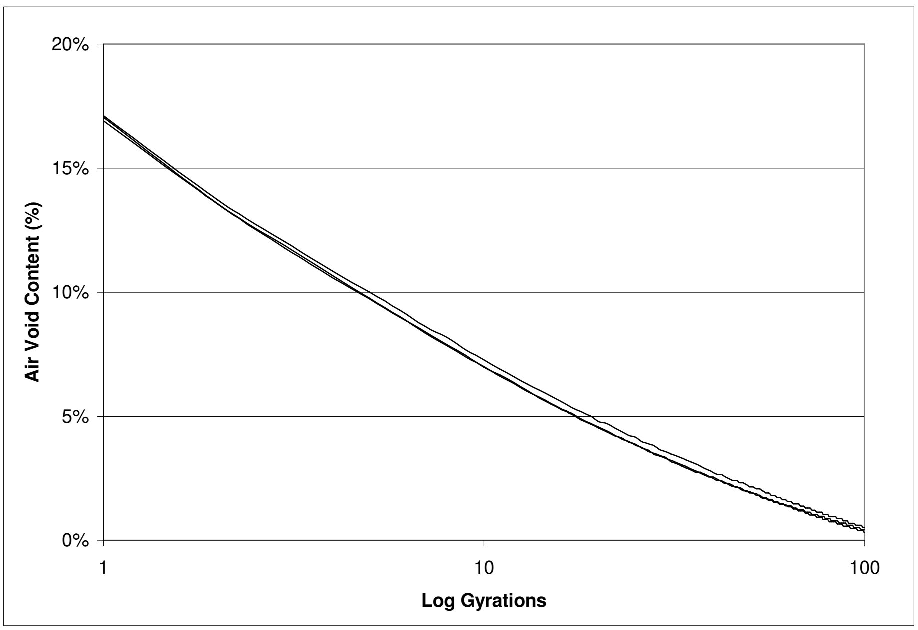

Figure 2. Representative Data for Superpave Gyratory Compaction Curves.

Discussion

Results from tests of HMA mixes designed using the Marshall 75-blow manual compaction effort showed expected trends for the design binder content at 3.5 percent air voids for each aggregate blend. The gradation of the aggregates was a factor affecting the design binder content. Aggregate blends with larger maximum sizes required lower percentages of asphalt. Introducing natural sand to asphalt mixes reduced the design binder content by altering particle interaction and aiding compaction.

Statistical analyses were performed on the $N_{equivalent}$ values. The statistics results are not included in this paper but are reported in Rushing [23]. Results from the statistical analysis suggest that natural sand content, aggregate type and gradation, and binder type all influence the $N_{equivalent}$ for Superpave gyratory compaction. In the initial development of compaction requirements, there were 28 compaction levels [9]. The process was too cumbersome for practical implementation. Further modifications reduced the compaction requirements to four levels, dependent upon traffic. Currently, two compaction requirements, 50 and 75 blows of the Marshall hand hammer exist for designing asphalt mixes for airport pavements depending on the expected traffic [2]. This study only addresses the correlation for the 75-blow Marshall hand hammer method at a design air void content of 3.5 percent.

Results from this study indicate that the average $N_{equivalent}$ value for compacting HMA mixes to 3.5 percent air voids was 69 gyrations, but the standard deviation, 25, of these data was large. This type of variability in the data should be considered in final selection of N_{design}.

Table 4.
Summary of SGC Nequivalent Values.

Aggregate Type	Maximum Aggregate Size (in.)	Gradation	Percentage of Natural Sand	$N_{equivalent}$ [a]	
				PG 64-22	PG 76-22
Granite	1/2	Fine	0	80	125
			10	50	99
		Coarse	0	85	125
			10	43	65
	3/4	Fine	0	30	125
			10	94	104
		Coarse	0	45	81
			10	40	76
	1	Fine	0	65	106
			10	35	80
		Coarse	0	43	67
			10	68	79
Limestone	1/2	Fine	0	93	86
			10	35	52
		Coarse	0	61	60
			10	39	53
	3/4	Fine	0	76	55
			10	49	66
		Coarse	0	68	75
			10	42	61
Chert Gravel	1/2	Center	0	62	61
			10	21	46
	3/4	Fine	0	54	44
			10	39	38
		Coarse	0	35	52
			10	25	49

[a] Equivalent Gyrations Required to Compact Mixes to 3.5% Air Voids. Compaction ceased at 125 gyrations.

Based upon a survey of state transportation department procedures for designing asphalt mixes for high traffic roads, an N_{design} for airport mixes is recommended to be no fewer than 60 and no more than 90 gyrations. These recommendations are made based on the fact that the same traffic levels for highways were previously designed by the 75-blow manual Marshall compaction effort. Selecting the best value requires an acknowledgement of the effect of N_{design} on the resulting mix proportions. Two cases may exist if the number of gyrations specified for N_{design} is not in the appropriate range.

If the N_{design} value is set too low, asphalt mixes will be designed with too much asphalt cement. This result can lead to an asphalt mix design that is susceptible to rutting. Rutting is more likely because the air void content will be too low and viscous flow can occur. Additionally, excess asphalt cement in the mix will increase the mix cost.

If the N_{design} value is set too high, asphalt mixes will be designed with too little asphalt cement. This result can lead to premature failure due to decreased durability of the pavement. Durability problems exist because the air void content is too high in the mix. Mixes with excessive air voids are prone to weathering, raveling, and stripping. Having a high N_{design} value may also result in mixes that are difficult to compact in the field because of decreased lubrication from the binder. If the laboratory compaction effort is increased, the required field compaction effort will also increase. This result can lead to problems during pavement construction.

Data showed that the mixes containing the polymer-modified binder required a higher number of gyrations to compact than the mixes containing the unmodified binder. However, research has shown that polymer-modified HMA does not densify as much as its unmodified counterpart with traffic [24]. These results led to the recommendation of a lower N_{design} value when using polymer-modified HMA on highway pavements. According to the data, specifying the same design gyration level for unmodified and polymer-modified mixes would lead to an increase in the design binder content for polymer-modified mixes.

Selection of a recommended N_{design} value is made by taking the mean value of all of the $N_{equivalent}$ values determined in this study. Using the mean value acknowledges the balance in mix properties that result from changes in N_{design}. Although the mean of all $N_{equivalent}$ values was 69, an N_{design} value of 70 is recommended for simplicity.

Further analysis was performed to evaluate the impact of N_{design} on the AC content of the mix. Each mix was evaluated to determine the air void content at 70 gyrations. Then the air void content at other numbers of gyrations was identified. Each mix was evaluated at 10 and 20 gyrations above and below 70 gyrations. Figure 3 shows the average change in air void content as the number of target gyrations changes. At 50 gyrations, mixes had an average air content of 0.93 percent higher than the air content at 70 gyrations. At 60 gyrations, mixes had an average air content of 0.42 percent higher than the air content at 70 gyrations. At 80 gyrations, mixes had an average air content of 0.35 percent lower than the air content at 70 gyrations. At 90 gyrations, mixes had an average air content of 0.65 percent lower than the air content at 70 gyrations.

The data in Figure 3 show a greater effect on the air void content occurs by lowering the number of gyrations. This result is expected since the rate of compaction decreases with increasing gyrations. These data also show that small changes (10 gyrations) in N_{design} do not result in large changes (greater than 0.5 percent) in the air void content. Since the AC of the mix is adjusted to achieve a target air content of 3.5 percent, the changes in N_{design} would result in a change in the selected AC content. The changes in selected AC content are expected to be lower than the observed changes in air void content since additional AC would aid compaction.

In the mix design procedure, specifications provide tolerances on binder content accepted for use. These have been adjusted to ensure that quality asphalt mixes are used for airport pavements. Historically, adjustments to these tolerances have been made with empirical evidence. Most of the current specifications do a satisfactory job in ensuring acceptable performance. Until an effective performance test for asphalt mixes is included in design specifications, these property measurements will continue to provide a system of checks and balances for designing asphalt mix proportions.

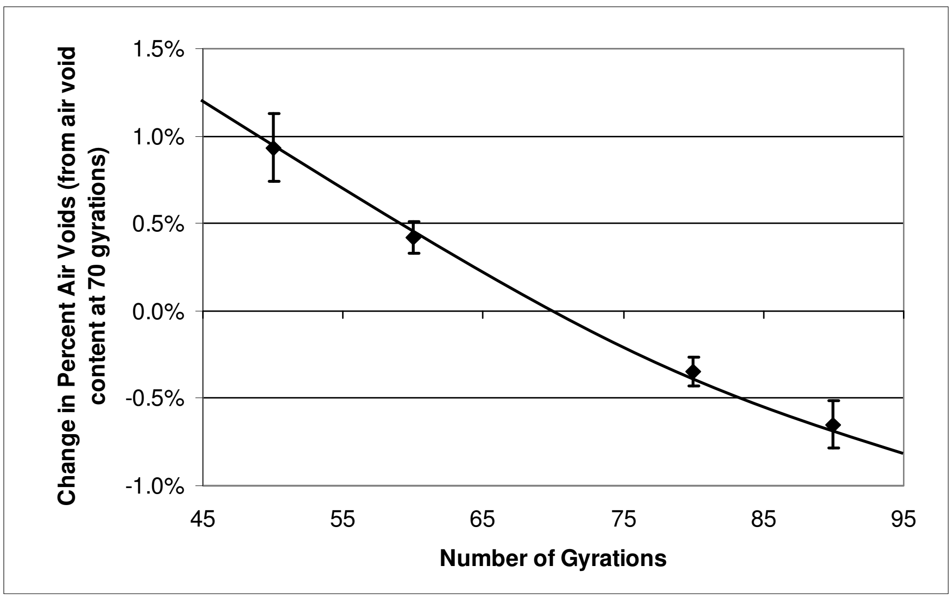

Figure 3. Influence of Number of Gyrations on Air Void Content.

The Superpave asphalt mix design system for highway pavements has used SGC compaction levels with which to evaluate additional asphalt volumetric properties at $N_{initial}$ and N_{max}. Guidance in FAA Engineering Brief 59A for designing asphalt mixes using the SGC for airports also includes specifications for these values. The criteria at $N_{initial}$ have been used to ensure that asphalt mixes that compact too easily are eliminated in the design process. These mixes include those that would be susceptible to rutting. The N_{max} value used in this method ensures that mixes do not continue to densify with increasing traffic.

Although these criteria were not used in this study, analysis of the gyratory compaction curves indicates that several of the asphalt mixes used would not pass the criteria in FAA Engineering Brief 59A for volumetric properties at either $N_{initial}$ or N_{max} at the binder contents used in the mixes. In fact, only 46 percent passed both criteria. A total of 55 out of 155 (35 percent) specimens did not meet $N_{initial}$ criteria defined in Engineering Brief 59A. Additionally, 84 out of 155 (54 percent) did not meet N_{max} criteria defined in Engineering Brief 59A. Those that do not meet these criteria are generally mixes containing the chert gravel aggregate or those containing 10 percent natural sand. This result indicates that the aggregate texture and angularity strongly influence compaction.

Additionally, $N_{initial}$ and N_{max} impart additional limitations on the flexibility of the mix design. They also lead to the tendency to limit the amount of asphalt cement in the mix. Both of the criteria can be achieved more easily if the AC content is reduced. Reducing the AC content is undesirable for airport pavements since they typically fail from environmental-related distresses.

In NCHRP 9-9(1), Prowell found that a high percentage of highway pavements that were providing good performance in the field failed $N_{initial}$ and N_{max} criteria [24]. Those that failed $N_{initial}$ and N_{max} criteria were typically fine-graded mixes. Prowell's results agree with the data presented above since airport mixes are considered fine-graded by Superpave standards. He determined that these values were not a good indication of rutting and that they should be eliminated from the design procedure.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Based on the results of this research study, the following conclusions can be made:

1. The design binder content obtained from the Marshall 75-blow compaction effort (3.5 percent air voids) was used to compact mixes in the SGC. The number of gyrations required to produce equivalent density had a mean value of 69 and standard deviation of 25.

2. The mean value of all $N_{equivalent}$ values was selected for N_{design}. Further analysis was performed to determine the effect of N_{design} on the air void content of the mixes. Changing the N_{design} value by 10 gyrations was determined to result in less than a 0.5 percent change in air void content.

3. Mixes were evaluated according to criteria for $N_{initial}$ in Engineering Brief 59A. Thirty-five percent of the mixes failed the criteria at the binder content used for sample compaction. Using this criterion would result in eliminating 35 percent of mixes that meet all criteria for the Marshall mix design procedure.

4. Mixes were evaluated according to criteria for N_{max} in Engineering Brief 59A. Fifty-four percent of the mixes failed the criteria at the binder content used for sample compaction. Using this criterion would result in eliminating 54 percent of mixes that meet all criteria for the Marshall mix design procedure. No determination has been made if these mixes would be susceptible to rutting in the field or in service.

5. Only 36 percent of mixes pass both $N_{initial}$ and N_{max} criteria in Engineering Brief 59A. However, these mixes were designed at 3.5 percent air voids; mixes in the criteria are designed at a lower binder content producing 4.0 percent air voids.

Recommendations

Based on research conducted in this study, the following recommendations are made:

1. The specification for designing asphalt mixes for aircraft greater than 60,000 lb gross weight can use an N_{design} of 70 gyrations. This N_{design} value should be further researched in laboratory and field studies prior to acceptance in future FAA criteria.

2. Additional research is recommended to determine the applicability of $N_{initial}$ and N_{max} criteria when designing asphalt mixes for airports. Currently, a recommendation is made that these values be eliminated from the mix design procedure since they will reject a high percentage of mixes that are deemed satisfactory by the Marshall mix design criteria. Mixes should be compacted to the N_{design} value in the laboratory for analysis.

3. Additional research is also needed to correlate field performance of asphalt mixes designed using Superpave methodologies. A performance test should be adopted to evaluate mixes in the laboratory. In-service pavements should be monitored to compare densities to those obtained in the laboratory design procedure to provide an indication of the prediction capability. In-service airport pavements should be monitored to determine if the ultimate density of the HMA with polymer-modified asphalt is similar to HMA with unmodified asphalt.

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